# Table of contents

# Table of exhibits

# 3  Automation

**Definition.  Automation** is the independent accomplishment of a function by a device or system that was formerly carried out by a human.  [Source: National Research Council (NRC), 1998; Parasuraman & Riley, 1997]

## 3.1  General

☐  **3.1.1  Minimum automation human factors requirements.**  An automated system should

    a.    provide sufficient information to keep the user informed of its operating mode, intent, function, and output;

    b.    inform the user of automation failure or degradation;

    c.    inform the user if potentially unsafe modes are manually selected;

    d.    not interfere with manual task performance; and

    e.    allow for manual override.  [Source: Veridian (AHCI), 1998; Billings, 1997]

■  **3.1.2  Place user in command.**  Automated systems shall prevent the removal of the user from the command role.  [Source: Billings, 1997]

> **Discussion.**  The reasoning behind this rule is twofold.  First, it is ultimately the user who is responsible for the task.  Second, automation is subject to failure.  Therefore, it is the user, not the automation who must be in control of the system with the automation playing a subservient role.  [Source: Billings, 1997]

■  **3.1.3  Automate only to improve performance.**  Functions shall be automated only if they improve system performance without reducing human involvement, situation awareness, or human performance in carrying out the intended task.  [Source: Billings, 1991]

> **Discussion.**  The introduction of automation is often intended to reduce workload and augment performance; however, this is not always the result.  Automation can lead to distraction from the primary task, increased workload, boredom, or complacency.  Automation can also have psychosocial impacts, influencing job satisfaction or self worth.  [Source: Bowers, Deaton, Oser, Prince & Kolb, 1995; Danaher, 1980; Edwards, 1976; Parasuraman, Molloy, Mouloua, & Hilburn, 1996; Wiener, 1989; Wiener & Curry, 1980]

▫ **3.1.4  Automate with good reason.**  Automation should be used to support the user(s) where appropriate (human-centered automation), not implemented simply because the technology is available (technology-centered automation).  [Source: Billings, 1997]

▪ **3.1.5  Enable users to carry out tasks.**  Automation shall help or enable the users to carry out their responsibilities and tasks safely, efficiently, and effectively.  [Source: Billings, 1991]

> **Definitions.**  Carrying out a task **effectively** means producing the desired result.  Carrying out a task **efficiently** means that the desired result is produced with a minimum of waste (usually in relation to time).

▪ **3.1.6  Provide a clear relationship with user tasks.**  The relationships between display, control, decision aid, and information structure and user tasks and functions shall be clear to the user.  [Source: Nuclear Regulatory Commission (NUREG-0700), 1996; Nuclear Regulatory Commission (NUREG/CR-6105), 1994]

> **Discussion.**  The user needs to be able to see clearly how the display or decision aid, and so on, facilitates the completion of the necessary task.

▪ **3.1.7  Ensure active user involvement in operation.**  Users shall be given an active role through relevant and meaningful tasks in the operation of a system regardless of the level of automation being employed.  [Source: AHCI, 1998; Billings, 1991]

> **Discussion.**  User awareness of system state cannot be sustained passively.  Active involvement is essential for operators to exercise their responsibilities and be able to respond to emergencies.  Reducing active involvement may be detrimental to the user's understanding of important information, may lead to longer response times in case of emergencies, or, in the long term, may lead to loss of relevant knowledge or skills.  [Source: Galster, Duley, Masalonis, & Parasuraman, 2001; Garland & Hopkin, 1994; Hopkin, 1988; Sarter & Woods, 1992 (as found in Scerbo, 1996); Wickens, 1992 (as found in Scerbo, 1996)]

▫ **3.1.8  Make procedures suitable to user expertise.**  Procedures employed in automation should be appropriate to the user's level of expertise with the system.  [Source: Defense Information Systems Agency (DISA), 1996]

> **Example.**  Shortcuts such as function keys can be provided for the more experienced users, whereas novice users can still use standard procedures.

▢ **3.1.9  Implement based on goals for system.**  How automation is implemented should be determined by the explicit goals of the system, not by comparison between automated and manual systems.  [Source: Wiener & Curry, 1980]

> **Discussion.**  When automation is implemented, explicit goals of the system need to be kept in mind, thus, an automated system does not need to perform a task the same way as it was performed manually to be effective.

▢ **3.1.10  Avoid increasing demands for cognitive resources.**  Automation should not increase the demands for cognitive resources (thinking or conscious mental processes).  [Source: Bainbridge, 1983; Parasuraman & Riley, 1997; Wiener & Curry, 1980; Woods, 1996]

> **Discussion.**  Automation that increases the demand for cognitive resources is poorly designed.  Expert users in complex, dynamic systems have been observed to cope with poorly designed automation by using only a subset of the available functionality, especially during periods of high workload.  [Source: Woods, 1996]

▢ **3.1.11  Avoid extreme workload levels.**  Extreme levels of workload (low or high) due to automation use should be avoided. [Source: Hilburn, Jorna, Byrne, & Parasuraman, 1996; NRC, 1993; Warm, Dember, & Hancock, 1996; Wiener, 1988]

> **Discussion.**  Extreme levels of workload can be caused by poorly designed automation.  Poorly designed automation can cause extreme workload levels by increasing workloads when they are already high (for example, for pilots, during the high workload flight phases of take-off and landing) and decreasing workloads that are already low (for example, providing a pilot with the ability to engage autopilot during the low workload "cruise" phase of a flight).  Automation is often introduced to reduce workload.  However, reduction of workload may not always be advantageous, for example, if workload is already low.  [Source: Hilburn et al., 1996; Parasuraman & Mouloua, 1996]

▪ **3.1.12  Prevent distraction from operations.**  User interaction with automation shall not require the user to take significant amounts of attention away from the primary task.  [Source: Danaher, 1980]

> **Discussion.**  When automation requires the user or one member of the user team to devote a significant amount of attention to adjusting or monitoring the automation, this removes the user away from minute-to-minute operations, thereby taking the user out of the loop.  This can be especially dangerous if an abnormal situation occurs that needs to be remedied quickly.  [Source: Danaher, 1980]

□ **3.1.13  Avoid interruption at inappropriate times.**  Automation should not interrupt at inappropriate times such as during periods of high workload or during critical moments in a process.  [Source: Woods, 1996]

> **Discussion.**  An interruption during high workload or at a critical moment can cause a delay in the user's ability to respond to a malfunction, leading to a potential failure.  If the user is attending to a malfunction in an automated task and is interrupted, the interruption depletes the user's mental resources causing him to be less capable of averting the potential failure.  For example, in the cockpit, certain automation functions might be stopped from interrupting during the takeoff and landing portions of flight.

□ **3.1.14  Make tasks easier to perform.**  An automated task should be less difficult to perform than the manual task it replaces. [Source: AHCI, 1998]

□ **3.1.15  Guide the use of automation.**  Standard operating procedures and company policies should guide users in the appropriate use of automation, although the user should be ultimately responsible to make the decision to use or not use the automation.  [Source: Billings, 1997; Parasuraman & Riley, 1997]

■ **3.1.16  Provide easy data access.**  Data that are needed by the user shall be easily accessible.  [Source: NUREG/CR-6105, 1994; NUREG-0700, 1996]

> **Discussion.**  User requirements can serve as a guide of whether the data are available at all times, accessible at the users' discretion, or not at all if the user does not need information.

□ **3.1.17  Prompt for data entry format.**  The automated system should prompt users as to the correct data entry format.  [Source: Billings, 1996]

> **Example.**  If the automated system requires that the data be entered in all capital letters, it should specifically tell the user to enter the data in capital letters.

□ **3.1.18  Make it error resistant and error tolerant.**  Automation should be error resistant and error tolerant.  [Source: Billings, 1991]

> **Discussion.**  To make a system **error resistant** is to make it difficult for a user to make an error.  Simplicity in design and the provision of clear information are tools to improve error resistance.  **Error tolerance** is the ability to mitigate the effects of human errors that are committed.  Error tolerance can be improved by adding monitoring capabilities to the automation.  Electronic checklists also have the potential to improve error resistance by providing reminders of items that need to be completed.  [Source: Billings, 1991]

▪ **3.1.19  Make system behavior predictable.**  Automated systems shall behave predictably so that the user knows the purpose of the automation and how the operation will be affected by that automation.  [Source: Billings, 1991, 1996]

> **Discussion.**  The predictability of an automated system allows the user to know what to expect when the automation is functioning correctly.  This makes it easier for the user to recognize when the system is not functioning.  [Source: Billings, 1996]

▪ **3.1.20  Ensure safe operations are within human capacity.**  Systems shall not be so reliant on automation or on human skills degraded by automation use that human users can no longer safely recover from emergencies or operate the system manually if the automation fails.  [Source: Billings, 1996; NRC, 1998]

> **Discussion.**  A balance is needed between the efficiency created by automation, the need for the operator to be able to recover from emergencies, and control the system manually in case the automation fails.

▫ **3.1.21  Provide means of user override.**  The automation should not be able to veto user actions leaving the user without means to override or violate the rules that govern the automation unless there is not enough time for the user to make a decision.  [Source: Garland & Hopkin, 1994; Inagaki, 1999]

> **Discussion.**  Problems with automation can occur when the automated options do not apply to a situation and the user is restricted to the options provided by the automation.

▪ **3.1.22  Provide interaction consistency.**  The way that automation systems interact with their users shall reflect a high degree of consistency within and between systems.  [Source: NUREG-0700, 1996]

> **Discussion.**  There are many possible types of interaction, such as menu selection, direct manipulation, and form-filling.  (See Chapter 8 on computer-human interfaces for more information on interaction).  An example of inconsistent interaction would be having one system require filling in forms as the interaction method, whereas another system requires menu-driven interaction.

▫ **3.1.23  Make systems easy to understand and use.**  Automated systems and associated integrated information displays should be intuitive, easy to understand, and easy to use.  [Source: Billings, 1991; Sarter & Woods, 1994; Woods, 1996]

> **Discussion.**  System operations that are easily interpretable or understandable by the user can facilitate the detection of improper operation and the diagnosis of malfunctions.  [Source: Wiener & Curry, 1980]

▫ **3.1.24  Make systems simple to learn.**  Automation should be simple for the users to learn.  [Source: Billings, 1991; Wiener & Curry, 1980]

▫ **3.1.25  Provide means to check input and setup data.**
Automated systems should provide a way to check automation setup and to check information used as input for the automated system.  [Source: Wiener & Curry, 1980; Wickens, 2000]

> **Discussion.**  Automation failures are often due to setup error.  Although the automated system itself could check some of the setup, independent error-checking equipment or procedures may be needed.  The user needs to be able to distinguish whether a failure occurred due to the automation setup or due to an inaccuracy in the input information.  An automation failure could have been caused by a malfunction of an algorithm or by the input of inaccurate data.  For example, if the automated system relies on primary radar and secondary radar as inputs and uses an algorithm to predict conflicts, a failure could arise from faulty data from either the primary or secondary radar or from the algorithm that combines this information.  [Source: Wiener & Curry, 1980; Wickens, 2000]

## 3.2  Design and evaluation

▫ **3.2.1  Involve users in design.**  Users should be involved in the design of an automated tool.  [Source: Amalberti, 1999; Billings, 1997; Parasuraman, Sheridan, & Wickens, 2000]

> **Discussion.**  Input from the user is essential in defining information requirements.

▫ **3.2.2  Design based on human-centered goals and functions.**
Design of automation should begin by choosing the human-centered criteria (goals) of the system and then defining the functions that the system will perform.  [Source: Wiener & Curry, 1980]

> **Discussion.**  Defining the goals and functions of an automated system may require the use of task analysis.

■ **3.2.3  Consider effect on coordination.**  When new automation is introduced, the designers shall consider the possibility of negative effects on team coordination.  [Source: Wiener, 1989]

> **Discussion.**  Automation may deplete team interaction and cooperation unless all parties are provided with information that allows them to be actively involved in the task.  Automation can cause physical difficulty in seeing what the other team member is doing, reduce the ability to cross monitor, change traditional roles and responsibilities, and change the manner in which team members attempt to help one another.  [Source: Danaher, 1980; Rudisill, 1994]

- **3.2.4 Assess overall impact.** The overall impact of automation shall be thoroughly examined before implementation to ensure that changes do not result in additional complexities, loss of situational awareness, or possibilities for error. [Source: Woods, 1996]

  > **Discussion.** Automation of some user tasks may result in the user processing less information or processing information at less depth. A diminished understanding and appreciation for the overall situation may result. [Source: Garland & Hopkin, 1994]

- **3.2.5 Validate system design.** Contextually valid human-in-the-loop experiments and simulations should be conducted to validate and refine automated system design. [Source: NRC, 1998]

- **3.2.6 Evaluate interactions with other functions.** Possible interactions with other tools, system functions, and user tasks shall be evaluated when new automation is designed. [Source: NRC, 1998]

- **3.2.7 Test as a whole.** New automation components shall be tested with the complete system, including other automated components of the system, to ensure they function together as an effective whole. [Source: NRC, 1998]

- **3.2.8 Test normal and failure modes.** Automated systems shall be tested under normal modes of operation and under failure modes of the automation. [Source: NRC, 1998; Wickens, 2000]

- **3.2.9 Test before implementation.** Automated systems shall be tested in a realistic operational environment with representative users before implementation to ensure that operator performance is not compromised and workload is not increased. [Source: Drury, 1998]

## 3.3  System response and feedback

- **3.3.1 Visualize consequences of decisions.** The user should be able to visualize the consequences of a decision, whether made by the user or the automated system. [Source: Billings, 1996]

- **3.3.2 Provide brief and unambiguous command response.** Automated system responses to user commands should be brief and unambiguous. [Source: Billings, 1997]

- **3.3.3 Keep users aware of function.** The automated system should keep the user aware on a continuing basis of the function (or malfunction) of each automated system and the results of that function (or malfunction). [Source: Billings, 1996]

□   **3.3.4 Provide effective feedback.** Automation should provide
the user with effective feedback on its actions and the purpose of
these actions.  [Source: Woods, 1996]

> **Discussion.** When feedback is poor, automation is
> considered silent.  Silent automation may result in
> coordination and system failures.  Users may be surprised
> by the behavior of silent automation.  [Source: Woods, 1996]

# 3.4  Interface

□   **3.4.1  Keep it simple.** The automation interfaces should represent
the simplest design consistent with functions and tasks of the users.
[Source: NUREG-0700, 1996]

> **Discussion.** Simplicity for the user is achieved by
> attaining compatibility between the design and human
> perceptual, physical, cognitive, and dynamic motor
> responsiveness capabilities.  (See Chapter 8 on computer-
> human interfaces for more information on interface
> design.)  [Source: NUREG-0700, 1996]

■   **3.4.2 Provide interface consistency.** Human interfaces in
automation programs and systems shall have a high degree of
consistency.  [Source: NUREG-0700, 1996]

> **Discussion.** Consistency can be obtained by presenting
> information in predictable locations and keeping elements
> of screens such as headers, fields, and labels consistent in
> appearance and relative location throughout a system or
> application.  (See Chapter 8 on computer-human
> interfaces for more information on interface design.)
> [Source: Shneiderman, 1998]

□   **3.4.3 Be consistent with user expectations.** Automated systems
and interfaces should be consistent with the expectations and
understandings of users.  [Source: Billings, 1991, 1996]

■   **3.4.4 Make interface structure logical.** Automation interfaces
shall reflect an obvious logic based on user task needs and
capabilities.  [Source: NUREG/CR-6105, 1994; NUREG-0700, 1996]

■   **3.4.5 Make location status obvious.** Interfaces and navigation
aids shall make it easy for users to know where they are in the data
space.  [Source: NUREG/CR-6105, 1994; NUREG-0700, 1996]

□   **3.4.6 Use spatial representations where possible.** Where
possible, spatial representations of information should be used
instead of verbal or textual displays in high workload situations.
[Source: Barnes, 1981]

> **Discussion.** Although humans are often better able to
> attend to spatial representations, it is not always easy or
> even possible to create spatial representations of
> information.  [Source: Barnes, 1981]

□  **3.4.7 Present dynamic information in real time.**  Dynamic information (information that changes over time) should be presented in real time and on demand to ensure accurate and timely decision-making.  [Source: Morris, Rouse, & Ward, 1985]

## 3.5  User acceptance and trust

□  **3.5.1 Increasing user trust in automation.**  To increase user trust in automation, automation performance should be

a.  reliable and predictable with minimal errors,

b.  robust (able to perform under a variety of circumstances),

c.  familiar (use terms  and procedures familiar to the user), and

d.  useful. [Source: Lee & Moray, 1992; Lerch & Prietula, 1989; Masalonis & Parasuraman, 1999; Muir, 1987 (as found in Riley, 1996); NRC, 1998]

**Discussion.**  Trust in automation tends to be relatively stable.  However, changes in trust may occur over time. User trust in automation can increase with reliable and predictable performance.  Decreases in trust may occur as a result of some critical error or automation failure.  It is more difficult for users to regain trust in automation after a failure than to develop an initial trust.  Higher trust in automation is not always better because automation errors may be overlooked due to complacency.  Decreases in trust typically occur suddenly, but increases happen slowly and steadily.  The consequences of an automation failure (for example, the magnitude of an error) impact the decline in trust.  [Source: Lee & Moray, 1992; Lerch & Prietula, 1989; Masalonis & Parasuraman, 1999; Riley, 1996; NRC 1998]

□  **3.5.2 Provide training for users to develop trust in automation reliability.**  Training should be provided to enable the user to calibrate their trust in the automated system. [Source: Cohen, Parasuraman, & Freeman, 1998]

**Discussion.**  Training will allow the user to develop an adequate model of how reliable or unreliable the automation is under specific conditions.

□  **3.5.3 Ensure automation availability.**  The automated system should be available to the user as needed.  [Source: Morris, Rouse, & Ward, 1985]

■  **3.5.4 Prevent interference with user tasks.**  The automated system shall not interfere with task performance.  [Source: Andes, 1987]

**Discussion.**  A user will be less likely to accept an automated system that interferes with their ability to perform tasks.  [Source: Andes, 1987]

▪ **3.5.5  Provide accurate and reliable information.**  Automation shall provide accurate and reliable information.  [Source: Andes, 1987]

> **Discussion.**  When users believe automation to be highly reliable, they place greater trust in it.  However, there is a trade-off involved with a constant high level of automation reliability and predictability.  Constant high levels of automation reliability and predictability may be more likely to promote complacency and may cause users to monitor automation with less vigilance.  [Source: Dzindolet, Pierce, Beck, & Dawe, 1999; Parasuraman, Molloy, & Singh, 1993, (as found in Masalonis & Parasuraman, 1999); Wiener, 1981]

▫ **3.5.6  Minimize changes due to automation.**  Changes in cognitive processing, ways of thinking, and methods and skills used for new automation should be minimized.  [Source: Garland & Hopkin, 1994]

> **Discussion.**  Automation that requires different kinds of cognitive processing, ways of thinking, and discarding of traditional methods and skills may cause the system to be both less efficient and less acceptable to the users.  This could include automatic conversion of data into a usable format.  [Source: Garland & Hopkin, 1994]

▫ **3.5.7  Promote understanding of automation function.**  To promote user acceptance of automation, users should be taught how an automated system functions.  [Source: Cohen, Parasuraman, & Freeman, 1998; Dzindolet et al., 1999; Lehner, Mullin, & Cohen, 1989]

> **Discussion.**  The better the user understands the automation, the more likely the user is to trust the automation appropriately.  Designers need to alter the false belief that automation is perfect and ensure that the users understand when the automation is likely to become unreliable. [Source: Dzindolet et al., 1999]

# 3.6  Modes

▫ **3.6.1  Clearly identify modes and functions.**  When control, display, or automation functions change in different modes of operation, mode and function identification and status should be clear.  [Source: Billings, 1991; Sarter & Woods, 1995]

> **Discussion.**  Lack of effective feedback on the state of automation (including which mode is active) can lead to mode errors.  [Source: Sarter & Woods, 1995]

▫ **3.6.2 Identify alternatives in rarely used modes.** Seldom-used modes and functions should be clearly identified. [Source: Billings, 1991]

> **Example.** As automated systems become more complex with many modes and functions, the cognitive burden caused by the need for mode awareness increases. Seldom-used modes and functions will pose the largest burden on the user because of a lack of familiarity. Enabling the user to immediately recognize the purpose of modes and functions, such as labeling the engine failure function "ENG OUT," can lessen this burden. [Source: Billings, 1997]

▫ **3.6.3 Make frequently used modes easy to get to.** Frequently used modes should be more accessible than infrequently used modes. [Source: AHCI, 1998]

▫ **3.6.4 Number of modes.** The number of different modes for a given system should be minimized. [Source: AHCI, 1998]

> **Discussion.** Multiple modes will provide a means of flexibility but will introduce more opportunities for error. Furthermore, automation that has multiple modes of operation can be difficult to learn and can produce increases in workload. Users must understand and remember how and when to use each mode, and they must remember which mode is currently active. [Source: Scerbo, 1996; Woods, 1996]

▫ **3.6.5 Allow switching between modes.** The user should be able to easily switch between modes. [Source: AHCI, 1998]

▫ **3.6.6 Provide consistent features and functions.** Features and functions that are common between display modes should be consistent. [Source: AHCI, 1998]

> **Discussion.** In the original Standard Terminal Automation Replacement System (STARS), the Full Service Level (FSL) and the Emergency Service Level (ESL) had independent and inconsistent interfaces requiring users to learn two different interfaces: mouse interaction styles and status-coding schemes. This can lead to additional training requirements and workload. The human factors team recommended that the two subsystems have identical coding strategies, identical access and execution of system commands, consistent data display formatting, and consistent monitoring and reporting of resources. [Source: Standard Terminal Automation Replacement System Human Factors Team, 1997, 1998]

▫ **3.6.7 Alert user to potentially hazardous interactions.** The automated system should alert the user to the implications of interactions between modes, especially when they are potentially hazardous. [Source: Billings, 1996]

□    **3.6.8  Alert users of unsafe modes.**  The automated system should either prevent the use of potentially unsafe modes or alert the user that a particular mode may be hazardous.  [Source: Billings, 1996]

# 3.7  Monitoring

■    **3.7.1  Allow users to monitor automated systems.**  The system shall be designed so that users are able to monitor the automated systems and the functionality of its hardware and software, including the display of status and trend information, as needed. [Source: Billings, 1991]

   **Discussion.**  One way that this can be accomplished is by providing the user with access to raw data that the automation processes.

■    **3.7.2  Display changing data as graphic.**  Changing data that must be monitored by the users should be displayed in a graphic format.  [Source: Smith & Mosier, 1986]

□    **3.7.3  Make users active in control and monitoring.**  Automation should be designed so that users are involved in active control and monitoring rather than just passive monitors. [Source: Hilburn, Jorna, & Parasuraman, 1995; Wickens & Kessel, 1979]

   **Discussion.**  Automation failures may be easier to detect when users are involved in both active control and monitoring, than when they are just passive monitors. [Source: Hilburn, et al., 1995; Wickens & Kessel, 1979]

□    **3.7.4  Allocate cognitive resources for monitoring.**  System designers should allow adequate cognitive resources for monitoring by ensuring that task load does not become excessive. [Source: Wiener & Curry, 1980]

   **Discussion.**  Users of automated systems may experience higher levels of mental workload than manual controllers due to monitoring, diagnosis, and planning, with significant cognitive demand resulting from relatively "simple" vigilance tasks.  [Source: Deaton & Parasuraman, 1993; Sheridan, 1970; Warm et al., 1996]

□    **3.7.5  Limit monitoring time.**  Users should not be required to perform purely monitoring tasks for longer than 20 minutes at a time.  [Source: Parasuraman et al., 1993; Warm et al., 1996]

   **Discussion.**  Users may become complacent in monitoring automated systems if they have other tasks to complete simultaneously.  Such decrements in user monitoring of automated systems have been observed to occur in the laboratory in as little as 20 minutes.  [Source: Parasuraman et al., 1993; Warm et al., 1996]

□ **3.7.6 Integrate displays.** When users must monitor multiple displays, important events should occur in the same display in order to promote effective monitoring performance. [Source: Warm et al., 1996]

□ **3.7.7 Minimize spatial uncertainty.** Important events should occur in the same location on a display in order to promote effective monitoring performance. [Source: Warm et al., 1996]

> **Discussion.** Users will be able to detect a particular event more easily if they know where that event will occur (i.e., spatial certainty). Spatial uncertainty has been shown to increase perceived workload and decrease performance efficiency. If users do not know where on a display an event will occur then they must engage in visual scanning to look for the event. [Source: Adams & Boulter, 1964; Warm et al., 1996)]

□ **3.7.8 Provide indication of monitoring.** Automated systems that are without incident for long periods of time should provide some type of indication that the automation is still monitoring the system. [Source: AHCI, 1998]

□ **3.7.9 Warn of potential user errors.** Automated systems should be able to monitor user interactions and to warn of user errors. [Source: Billings, 1991]

> **Discussion.** To monitor user interactions and to warn of user errors, automated systems may need to be able to receive input information on user intentions.

□ **3.7.10 Monitor critical functions.** Critical automation functions should be independently monitored by the user. [Source: Billings, 1996]

> **Definition.** A **critical function** is a function that can cause system failure when a malfunction is not attended to immediately.

> **Discussion.** When a function is critical, combining the monitoring of that critical function with other, possibly less critical functions may lead to delays in response. When a critical function is independently monitored, a user can respond to a malfunction very quickly (within one second). If a user is attending to another task when there is a malfunction, there will be a delay in the user's response (several seconds). In this period of delayed response, the malfunction can cause the system to fail. For this reason, critical functions require constant attention. Critical automation functions do assist in the completion of critical tasks, however they do not assist in freeing the user to attend to other tasks. [Source: Parasuraman et al., 1996]

▫ **3.7.11 Ensure adequate understanding.** Users should be given an adequate understanding (mental model) of how the automated system works in order to monitor effectively. [Source: Carroll & Olsen, 1988 (as found in Scerbo, 1996); Wickens, 1992 (as found in Scerbo, 1996); Wickens & Flach, 1988; Woods, 1994 (as found in Scerbo, 1996); Woods, 1996]

> **Discussion.** Users must possess accurate mental models of automated systems in order to monitor effectively, comprehend current situations, plan their actions, predict future system states, remember past instructions, and diagnose system failures. One way to establish adequate mental models is through training. [Source: Scerbo, 1996; Wickens, 1992 (as found in Scerbo, 1996); Wickens & Flach, 1988; Woods, 1994 (as found in Scerbo, 1996); Woods, 1996]

▫ **3.7.12 Provide intermittent manual control.** Intermittent periods of manual control should be used during extended periods of task automation to improve monitoring of the automation. (See adaptive automation-Section 3.13.) [Source: Morrison, Cohen, & Gluckman, 1993; Parasuraman et al., 1993]

> **Discussion.** Complacency is a major concern with automation. Intermittent periods of manual control have been advocated as a means of minimizing complacency. Automation may also result in the decrement of cognitive abilities such as instrument scan and navigation/positional [situation] awareness and the loss of manual skills, making transitions from automated to conventional systems difficult. Because automation can decrease basic manual skills, these skills should be used and maintained. Intermittent periods of manual control during which automation is suspended periodically can promote optimal user performance, and allow better recovery from failure, regardless of the type of task that is automated. [Source: Endsley & Kiris, 1995; Morrison et al., 1993; Rudisill, 1994; Wickens, 1992 (as found in Scerbo, 1996)]

▫ **3.7.13 Minimize noise.** Environmental noise should be minimized to ensure optimal vigilance. [Source: Warm et al., 1996]

> **Discussion**. Vigilance will be reduced when high levels of intermittent noise are present in the environment, especially if the information processing task demands are high. Noise is defined as sounds that are loud, disagreeable or unwanted. Music, however, may act as a stimulant and offset decrements in arousal due to fatigue and prolonged performance. [Source: Davies, Lang & Shackleton, 1973; Hancock, 1984 (as found in Warm et al., 1996); Matthews, Davies, Westerman, & Stammers, 2000]

▫ **3.7.14  Consider circadian rhythm effects on performance.**
System designers should consider the effects of circadian rhythms
on user vigilance and monitoring performance.  [Source: Colquhoun,
1977 (as found in Warm et al., 1996)]

> **Discussion.**  It will be most difficult for users to maintain
> monitoring performance during the early morning (8:00
> a.m.) when body temperature is low.  Performance will
> peak late in the day (between 5:00 p.m. and 9:00 p.m.) as
> body temperature rises.  Monitoring performance will then
> decline again as body temperature drops.  Maintaining
> monitoring performance can also be difficult for users
> working irregular work schedules.  Working consecutive
> night shifts, prolonged work shifts, or starting hours that
> are too early can cause users to experience a
> desynchronization of their circadian rhythm caused by the
> accumulation of sleep deficit and fatigue.  [Source: Costa,
> 1999; Warm et al., 1996]

▫ **3.7.15  Consider potential vigilance decrements.**  The effects on
vigilance due to the use of automation should be considered
before introducing new automation.  [Source: Warm et al., 1996]

> **Discussion.**  A **vigilance decrement**, that is, a
> continuously decreasing ability to maintain attention over
> time while monitoring, may occur with the use of
> automation.
>
> Vigilance decrements do not occur because monitoring
> tasks are under stimulating.  Rather, they require a large
> amount of cognitive resources and are often frustrating.
> Vigilance decrements have been observed to occur for both
> expert and novice users in high fidelity simulations and
> real-world operations.  [Source: Baker, 1962; Colquhoun, 1967,
> 1977; Mackworth, 1948, 1961; Schmidke, 1976 (as found in Warm et
> al., 1996); Warm et al., 1996]
>
> How hard the user must work in order to maintain vigilance
> can be determined by at least two factors.  First, workload
> is affected by the ease with which relevant signals can be
> detected.  Signals that have low salience are more difficult
> to detect than signals high in salience.  Visual fatigue will
> also require more effort to be expended in order to detect a
> signal.  Second, musculo-skeletal fatigue associated with
> maintaining a fixed posture will increase the workload
> needed to perform optimal monitoring.  [Source: Dember,
> Warm, Nelson, Simons, Hancock, & Gluckman, 1993; Warm et al.,
> 1996]

# 3.8  Fault management

Fault management relates to how the user notices and recovers from system failures.  Such failures may or may not be detected by automation.  Fault management has been defined to include the four distinct tasks of detection, diagnosis, prognosis, and compensation. [Source: Rogers, Schutte, & Latorella, 1996]

- **3.8.1  Ensure safety should automation fail.**  Automated systems shall allow for manual control and preservation of safe operations should the automation of one or more components of the system, on which the automation depends, fail.  [Source: NRC, 1998]

    **Discussion.** The resumption of manual control needs to be within the capacity of the user, without relying on manual skills that may be degraded by the use of automation. [Source: NRC, 1998]

- **3.8.2  Make failures apparent.**  Automation failures shall be made unambiguously obvious to the user. [Source: AHCI, 1998; Billings, 1991]

    **Discussion.** Stress, preoccupation, and distraction may reduce the user's ability to detect faults. [Source: Rogers et al., 1996]

- **3.8.3  Provide adequate early warning notification.**  Early warning notification of pending automation failure or performance decrements should use estimates of the time needed for the user to adjust to task load changes due to automation failure. [Source: Morrison, Gluckman, & Deaton, 1990]

    **Discussion.** In situations where automation failure would require user intervention, it is useful for the user to be warned that he or she will need to take manual control before the automated system fails.  Ideally, this warning needs to come in adequate time to allow the user to adjust to the new task load.  There may, however, be cases where it is not possible to provide advance notification of pending failure or where the estimate of time needed for the user to take control is unknown. [Source: Morrison et al., 1990]

- **3.8.4  Inform user of potential failure.**  The user shall be informed of automation performance decrements, potential failures, and malfunctions. [Source: Billings, 1996]

    **Discussion.** It can increase workload for the user to continually monitor the automation for failure.  Advance knowledge about potential failures can also help the user prepare to take manual control.

- **3.8.5  Automate diagnostic aids.**  Fault isolation, inspection, and checkout tasks shall be automated to the extent practical. [Source: National Air Space Administration (NASA-STD-3000A), 1989]

■ **3.8.6  Incorporate automatic self-checking components.**  All essential electronic computer and peripheral components that are part of a system shall incorporate an automatic self-check diagnostic test of software and hardware, both at power up and at the request of the operator, to ensure they are functioning properly.  [Source: Department of Defense (MIL-STD-1472F), 1999]

■ **3.8.7  Provide capability for on-demand system check.**  On-demand system checkout shall be available.  [Source: NASA-STD-3000A, 1989]

■ **3.8.8  Make sensor status verifiable.**  The status of sensors on replacement units shall be verifiable with respect to accuracy and proper operation.  [Source: NASA-STD-3000A, 1989]

■ **3.8.9  Permit status verification without disassembly.**  When feasible, equipment shall permit verification of operational status prior to installation without the need for disassembly.  [Source: NASA-STD-3000A, 1989]

■ **3.8.10  Permit fault detection without disassembly.**  Equipment shall permit fault detection and isolation without removing components, through the use of built-in test, integrated diagnostics, or standard test equipment.  [Source: Department of Defense (MIL-STD-1800A), 1990; NASA-STD-3000A, 1989]

■ **3.8.11  Facilitate rapid fault detection.**  Equipment design shall facilitate rapid fault detection and isolation of defective items to permit their prompt removal and replacement.  [Source: MIL-STD-1472F, 1999; NASA-STD-3000A, 1989]

■ **3.8.12 Identify failures without ambiguity.**  Fault detection and isolation shall identify without ambiguity which component has failed.  [Source: MIL-STD-1800A, 1990; NASA-STD-3000A, 1989]

■ **3.8.13  Provide portable diagnostic tools.**  When built-in test equipment is not available, diagnostic tools or portable equipment shall be provided to aid in fault isolation.  [Source: NASA-STD-3000A, 1989]

□ **3.8.14 Identify first alarm event.**  Automated warning systems should provide a means for identifying the first event in a series of alarm events.  [Source: NUREG-0700, 1996]

> **Discussion.**  When a series of interrelated alarms occur, information identifying which component first exceeded the set threshold can be valuable in determining the initiating cause of a problem.  [Source: NUREG-0700, 1996]

□ **3.8.15  Provide sufficient diagnostic information.**  The user should be provided with sufficient information and controls to diagnose automated warning system operation.  [Source: Wiener & Curry, 1980]

> **Discussion.**  In order for the user to diagnose the automated system, diagnostics information needs to be self-explanatory and in plain English.  The diagnostic information must provide the user with the information they need without requiring the user to seek additional references, or a help function, to understand the problem and the recommended solution.

## 3.9  False alarms

□ **3.9.1  False alarm rates.**  False alarm rates should not be so frequent as to cause the user to mistrust the automated system.
[Source: NUREG/CR-6105, 1994; Parasuraman, Hancock, & Olofinboba, 1997; Wiener & Curry, 1980]

> **Discussion.**  The trade-off between alerting the user to off-normal conditions and the creation of nuisance alarms needs to be considered when determining appropriate alarm set points.  A system that is designed to minimize misses, at all costs, is likely to have frequent false alarms.  However, automated systems that have frequent false alarms are unlikely to be trusted or even tolerated.  When there is low probability that the alarm is a true alarm (the "cry-wolf" phenomenon), users tend to ignore, mistrust or turn off alarms.  Setting the false alarm threshold requires careful evaluation of the trade offs between missed signals and false alarms including not only the decision thresholds at which the system is set, but also the probabilities of the condition to be detected.  [Source: NRC, 1997]

□ **3.9.2  Inform users of the probability of a true alarm.**  Users should be informed of the inevitable occurrence of automation false alarms particularly when base rates are low.  [Source: NRC, 1998]

> **Discussion.**  When the probability of an event is low, the odds of a true alarm can be quite low for even a very sensitive warning system, causing inevitable false alarms.
> [Source: NRC, 1998; Parasuraman et al., 1997]

# 3.10  Training

▫ **3.10.1  Introducing new automation.**  New automation should be introduced with advanced briefing and subsequent training procedures.  [Source: Billings, 1997; NRC, 1998; Parasuraman & Riley, 1997]

> **Discussion.**  The introduction of new automation may introduce changes in traditional roles and responsibilities, a redistribution of authority for tasks or changes to the nature of the cognitive demands imposed on the human operator.  [Source: Bowers et al., 1995; Wiener, 1989]

▫ **3.10.2  Prepare users for changes.**  Before automation is introduced, users should be informed of associated changes and increases in the work effort, as well as the benefits associated with the automation.  [Source: DISA, 1996; Scerbo, 1996]

> **Discussion.**  The roles and responsibilities of the users, cognitive demands, and operational procedures may change as a result of introducing automation.  [Source: Bowers, Deaton, Oser, Prince, & Kolb, 1995]

▫ **3.10.3  Train users to understand automated functions.**  Initial training in the use of automation should be sufficient for the users to fully understand how the automation functions within the particular system, as well as how to use the automation.  [Source: Billings, 1997]

> **Discussion.**  Lack of knowledge and understanding of how automation works can make it difficult for users to assess potential problems and may result in improper use of automation.  [Source: Rudisill, 1995]

▫ **3.10.4  Train users to backup automation.**  Users should be provided with backup training in performing any tasks replaced by automation or in operating any backup systems replaced by automation.  [Source: DISA, 1996]

▫ **3.10.5  Train to recognize inappropriate use of automation.**
Users should be trained to recognize inappropriate uses of an
automated tool including automation bias (the use of automation
in a heuristic manner as opposed to actively seeking and
processing information).  [Source: DISA, 1996; Dzindolet, Pierce, Beck,
& Dawe, 1999; Mosier & Skitka, 1999]

> **Discussion.**  There are different categories of
> inappropriate automation use, including automation bias,
> ignoring or turning off the automation, and improper
> implementation of automation.
>
> Users may rely on automated decision aids in a heuristic
> manner (referred to as **automation bias**).  Using
> heuristics is to apply simple decision-making rules to
> make inferences or to draw conclusions simply and
> quickly.  Heuristics are useful principles having wide
> application, but may not be strictly accurate.  Usually a
> heuristic strategy is optimal, however, under certain
> conditions heuristics will be inappropriate and errors or
> misuse may occur.  Automation bias leads to errors of
> omission (failure to notice system anomalies when
> automation fails) and errors of commission (acceptance of
> automated decisions without cross-checking or in
> presence of contradictory information).  Training will help
> prevent automation bias and help the user learn to
> examine multiple sources of information before making a
> decision.  Early training on automation bias may reduce
> commission errors for users new to automation, but may
> be less likely to reduce omission errors or errors made by
> expert users.
>
> Inappropriate use of automation may be influenced by
> various individual factors such as self-confidence in
> completing the task, trust in the automation, differential
> effects of fatigue, and how all of these factors combined
> weigh into the decision making process.  Inappropriate
> use of automation can be due to misuse (automation bias,
> complacency), disuse (ignoring or turning off automation)
> or abuse (improper implementation of automation).
> [Source: Dzindolet et al., 1999; Lee & Moray, 1992; Mosier &
> Skitka, 1996; Mosier, Skitka, Dunbar, Burdick, McDonnell, &
> Rosenblatt, 1998; Muir, 1987 (as found in Scerbo, 1996);
> Parasuraman & Riley, 1997; Riley, 1996]

▫ **3.10.6  Train users when to question automation.**  Users should
be trained to recognize and understand the conditions under
which automation may be unreliable, and to learn the conditions
where it performs well (when or when not to question the
automation).  [Source: Cohen et al., 1998; Dzindolet et al., 1999]

> **Discussion.**  Users must learn not to categorically accept
> the recommendation of a decision aid.  Understanding the
> automation's weaknesses allows users to better judge how
> much they should trust the automation without becoming
> overconfident in its performance.  This recognition
> process may impose an additional workload on the user.
> [Source: Dzindolet et al., 1999]

▫ **3.10.7  Avoid over-reliance on automation.** Users should be trained not to become overly reliant on automation.  [Source: Mosier, Skitka, Heers, & Burdick, 1997; Parasuraman & Riley, 1997]

> **Discussion.** When users rely on automation too much they become susceptible to automation-induced complacency.  Monitoring failures are likely to occur when users become overly reliant on automation.  [Source: Mosier, Skitka, & Korte, 1994; Parasuraman et al., 1993]

▫ **3.10.8  Train for risk assessment and reduction.** Users should be trained on risk assessment and actions needed for risk reduction.  [Source: Mosier & Skitka, 1999]

■ **3.10.9  Train for failure recovery transitions.** Users shall be trained on transitioning from automated to conventional systems.  [Source: Rudisill, 1994]

> **Discussion.** If automation were to fail, users need to be skilled at both recognizing the failure and taking manual control.

▫ **3.10.10  Stress interaction skills.** Training programs should stress user-automation interaction skills and cognitive/problem solving skills rather than psychomotor skills.  [Source: Sarter & Woods, 1994]

> **Discussion.** Problems in automation may not be inherent in the technology itself.  Problems can arise due to limitations in the integration of the user and automation. The user and automation should be integrated by developing a joint, distributed cognitive system by means of training and design.  [Source: Sarter & Woods, 1994]

▫ **3.10.11  Train for changes due to automation.** When automation requires different kinds of cognitive processing, ways of thinking, and discarding of traditional methods and skills, then training should be designed to address problems related to these changes.  [Source: Garland & Hopkin, 1994]

▫ **3.10.12 Train to identify normal output.** Users should be trained on what constitutes the normal automation output so that the user can easily determine whether the system is functioning properly.  [Source: Morris, et al., 1985]

## 3.11  Function allocation/levels of automation

There are many possible levels of automation (see Exhibit 3.11) including: automation that automatically executes tasks, automation that performs tasks when pre-specified conditions are met, and automation that suggest a course of action or facilitates a decision.  [Source: Billings, 1997; NRC, 1998; Parasuraman et al., 2000]

**Exhibit 3.11  Levels of automation, from high to low.** [Source: NRC, 1998; Sheridan, 1996]

| |
|---|
| The system acts autonomously without human intervention |
| The system informs the user after executing the action only if the system decides it is necessary |
| The system informs the user after executing the action only upon user request |
| The system executes an action and then informs the user |
| The system allows the user a limited time to veto before executing an action |
| The system executes an action upon user approval |
| The system suggests one alternative |
| The system narrows the selection down to a few |
| The system offers a complete set of action alternatives |
| The system offers no assistance |

▫ **3.11.1  Evaluate function allocation alternatives.**  Alternative function allocations including fully manual, partially automated, fully automated, and adaptive allocation should be evaluated for feasibility and effectiveness.  [Source: Wiener & Curry, 1980]

▫ **3.11.2  Evaluate through simulation.**  Alternative schemes for the allocation of functions should be examined in the context of the whole system through the use of high fidelity simulations. [Source: Wiener & Curry, 1980]

> **Discussion.**  Because there may be multiple potential schemes in the allocation of functions, simulating these schemes in the context of the whole system will allow them to be evaluated properly.  A scheme that seems to be the most appropriate in regards to accomplishing a specific task may not be the best choice in relation to the functioning of the entire automated system.

▫ **3.11.3  Only automate functions performed well by machines.**  Only functions that are performed well by machines should be automated, not functions that are performed better by humans. [Source: Drury, 1998]

▫ **3.11.4  Automate full behavioral modules.**  Behavioral modules in their entirety should either be automated or preserved as manual subtasks, not fractionally (partially) automated.  [Source: Vortac, Barile, Albright, Truitt, Manning, & Bain, 1996]

> **Discussion.**  A behavioral module is a unitized set of actions that can be performed in an over-learned, automatic fashion with very little effort.  When a set of cognitive or behavioral actions is frequently performed together they will eventually form a module.  Automation that replaces only a portion of a module will produce no advantage in performance and may inhibit performance. [Source: Vortac et al., 1996]

□ **3.11.5  Give tasks requiring flexibility to user.**  Tasks that are performed in an unpredictable environment requiring flexibility and adaptability should be allocated to the user.  [Source: AHCI, 1998]

□ **3.11.6  Make roles and responsibilities clear.**  The automated system should make it clear whether the user or computer is supposed to perform a particular task at a specific time.  [Source: Parasuraman & Riley, 1997]

□ **3.11.7  Provide means for changing roles and responsibilities.**  The automated system should provide a means for changing the allocation of roles and responsibilities.  [Source: Parasuraman & Riley, 1997]

□ **3.11.8  Automation of high-risk actions or decisions.**  For system tasks associated with greater uncertainty and risk, automation should not proceed beyond the level of suggesting a preferred decision/action alternative.  [Source: NRC, 1998]

> **Discussion.**  High levels of automation can be used for tasks involving relatively little uncertainty and risk. [Source: NRC, 1998]

## 3.12  Information automation

> **Definition.  Information automation** includes information acquisition and integration.  This type of automation would include filtering, distributing or transforming data, providing confidence estimates and integrity checks, and enabling user requests.

□ **3.12.1  Indicate if data are incomplete, missing, uncertain, or invalid.**  The automated system should provide a means to indicate to the user that data are incomplete, missing, unreliable, or invalid or that the system is relying on backup data.  [Source: AHCI, 1998]

□ **3.12.2  Provide automatic update.**  When the displayed data are changed as a result of external events, the user should be provided with the option of having an automatic update of changed information.  [Source: AHCI, 1998]

□ **3.12.3  Provide multiple output formats.**  System designers should provide information in multiple formats (for example, text, graphics, voice, and video) to allow better communication and reduction of workload.  [Source: Scerbo, 1996]

> **Discussion.**  Communication will be improved by allowing information to be presented in the most understandable format.  Eliminating the need to translate information into a specific format will reduce workload. [Source: Scerbo, 1996]

▫   **3.12.4  Show accurate status.**  Information presented to the user should accurately reflect system and environment status in a manner so that the user rapidly recognizes, easily understands, and easily projects system outcomes in relation to system and user goals.  [Source: Endsley & Kiris, 1995; NUREG-0700, 1996]

▫   **3.12.5  Minimize errors.**  Error-prone conditions should be minimized by maintaining user awareness, providing adequate training, developing standard operating procedures, and fostering crew coordination.  [Source: Sheehan, 1995]

> **Discussion.**  Errors due to automation may arise from data entry errors, monitoring failures, system workarounds, and mode misapplication.  Error-prone conditions in automated systems may result from lack of mode awareness, lack of situation awareness, lack of systems awareness, increased heads down time, over-dependence on automation, and interrupted crew coordination.  Automation-related errors usually occur in conjunction with other factors such as haste, inattention, fatigue, or distraction.  [Source: Sheehan, 1995]

■   **3.12.6  Information displays.**  Information displays shall support and reinforce status and situation awareness at all times.  [Source: Billings, 1991, 1996]

> **Discussion.**  A primary objective of information automation is to maintain and enhance situation awareness.  However, too much information presented simultaneously may become cluttered and make visual search difficult, interfering with status, decision-making, or control.  It is important for the user to be able to easily locate needed information.  [Source: Billings, 1991]

> The user's ability to detect a signal while monitoring varies inversely with the rate at which neutral background events are repeated.  [Source: Lanzetta, Dember, Warm, & Berch, 1987; Parasuraman, 1979 (as found in Warm et al., 1996)]

▫   **3.12.7  Situation displays.**  Event data should be combined with a map background when the geographic location of changing events needs to be shown.  [Source: Smith & Mosier, 1986]

■   **3.12.8  Present information consistent with task priorities.**  Both the content of the information made available through automation and the ways in which it is presented shall be consistent with the task priorities.  [Source: Billings, 1996]

▫   **3.12.9  Cueing important information.**  When information must be updated quickly, the most important information should be cued to ensure it will be the first to be processed by the user.  [Source: Wickens, 2000]

> **Discussion.**  It is important that the cues be correct, as there may be significant costs of invalid cueing.  [Source: Wickens, 2000]

□ **3.12.10 Queue messages automatically.** Incoming messages should be queued automatically by the system so they do not disrupt current information handling tasks. [Source: Smith & Mosier, 1986]

□ **3.12.11 Highlight changed data.** Data changes that occur following automatic display update should be temporarily highlighted. [Source: Smith & Mosier, 1986]

□ **3.12.12 Store and prioritize lists of information.** Long lists of information, tasks, and so on, should be stored and prioritized by the automated aid to minimize the number of decision alternatives and reduce the visual processing load of human operators. [Source: Barnes, 1981]

□ **3.12.13 Integrate display elements only if performance is enhanced.** Display elements should only be integrated if it will enhance status interpretation, decision-making, situation awareness, or other aspects of task performance. [Source: Billings, 1991]

□ **3.12.14 Integrated displays.** Integrated displays should combine various information automated system elements into a single representation. [Source: Billings, 1996; Parasuraman et al., 2000]

> **Discussion.** Feedback information that is widely distributed among various indicators can result in insufficient monitoring of automation and/or mode confusion. In such cases, monitoring adequacy is limited by inefficient scanning patterns and information that is difficult to integrate. [Source: Mosier & Skitka, 1999]

□ **3.12.15 Automatically arrange information depending on status.** System information should be automatically reorganized into integrated or non-integrated arrangements depending on the current system status. [Source: Forester, 1987; Parasuraman, et al., 1996]

> **Discussion.** Integrated information arrangement allows the user to assess the overall status of the system. Integrating display components into aggregated arrangements may reduce the attention demands of fault detection. Non-integrated arrangement of components draws user attention to system errors or other relevant information. Presenting the information in a format relevant to the state of the system can facilitate the ability of the user to quickly and easily assess the system status. [Source: Forester, 1987; Parasuraman et al., 1996]

□ **3.12.16 Make cues equally prominent.** Automated and non-automated cues should be made equally prominent to enable users to collect confirming/disconfirming evidence before deciding on appropriate action. [Source: Mosier & Skitka, 1999]

> **Discussion.** Automation bias, the tendency to use automation in a heuristic manner, may be suppressed if other, non-automated sources of information are presented with salience equal to that of the automated information. [Source: Mosier & Skitka, 1999]

# 3.13  Adaptive automation

**Definition. Adaptive automation** is the real time allocation of tasks to the user or automated system in a flexible manner, changing the automation to meet current situational demands. Adaptive automation may benefit user performance by allowing the user to remain in active control of the system instead of becoming a passive observer.  Active control may prevent performance decrements associated with long-term monitoring, loss of situation awareness and manual skill degradation.  [Source: Morrison et al., 1990; NRC, 1998; Scerbo, 1996; Scerbo & Mouloua, 1999]

**Discussion.**  Laboratory experiments have shown that short periods of automation use (for example, 10-minute cycles of manual and automated control) do not result in performance decrements.  This suggests that intermittent periods of manual control may help to maintain performance in the presence of automation.  [Source: Gluckman, Carmody, Morrison, Hitchcock, & Warm, 1993 (as found in Scerbo, 1996); Parasuraman, Hilburn, Molloy, & Singh, 1991]

▫ **3.13.1  Help during high workload.**  Automation should be designed to adapt by providing the most help during times of highest user workload, and somewhat less help during times of lowest workload.  [Source: Billings, 1996; Parasuraman, Mouloua & Hilburn, 1998]

**Discussion**.  Research has shown that adaptive automation may reduce mental workload most effectively during periods of high taskload.  [Source: Hilburn et al., 1996]

▫ **3.13.2  When not to implement adaptive automation.**  Adaptive automation should not be implemented unexpectedly or at a time when the user may not desire the aiding.  [Source: Scerbo, 1996]

**Discussion.**  The timing of adaptation may have critical impact on user acceptance of automation.  Studies show that users prefer to be in control of the system.  However, there are times that automation may need to be initiated by the system, particularly when changes in workload occur rapidly or are unexpected by the user.  [Source: Harris, Goernert, Hancock, & Arthur, 1994 (as found in Scerbo, 1996)]

▫ **3.13.3  When to implement adaptive automation.**  Adaptive automation should be implemented at the point at which the user ignores a critical amount of information.  [Source: Sen, 1984]

> **Discussion.**  Fatigue (or other factors) may prevent users from recognizing the best time to utilize automation and performance decrements may consequently occur.  One indication that the user is being overloaded is an increase in the amount of information he must ignore in order to make a timely decision.  Thus, the designer can use a threshold critical amount of ignored information as an indicator that the user is overloaded and implement adaptive automation at that point (to help reduce workload).  What constitutes a critical amount of information can vary depending on the particular task and may best be determined on a system-by-system basis.  [Source: Harris, Hancock, & Arthur, 1993 (as found in Scerbo, 1996); Sen, 1984]

▫ **3.13.4  Adapt to skill of the user.**  Adaptive automation should be used to increase the performance of users with different skill levels.  [Source: Norico & Stanley, 1989]

> **Discussion.**  By adapting to the skill of the user, adaptive automation can increase the proficiency of the novice user and prevent frustration that might otherwise occur with complex systems.

▫ **3.13.5  Make adaptive automation at least as skilled as user.**  Adaptive automation should be at least as skilled as the user, if not greater, to promote optimal user performance.  [Source: Woods, 1996]

▫ **3.13.6  Modeling of human behavior.**  Modeling of human behavior for aid-initiated intervention should at least include: task execution goal states, environment representation (graphical), situation assessment information and planning, and commitment logic.  [Source: Andes & Hunt, 1989]

> **Discussion.**  When modeling user behavior, it ought to be noted that users vary greatly in the way they employ automation.  [Source: Lee, 1992; Lee & Moray, 1992 (as found in Riley, 1996)]

▫ **3.13.7  Interface adaptation.**  When dynamic adaptation of the interface is used, it should be attained by utilizing information provided to the system through user interactions within a specific context. [Source: Norico & Stanley, 1989]

> **Discussion.**  Dynamic adaptation of the interface may promote operator acceptance of automation.

▫ **3.13.8  Menu adaptation.**  When dynamic adaptation of menus is used, the resultant menus should offer only the options that are relevant to the current environment.  [Source: Barnes, 1985]

> **Discussion.**  Dynamic adaptation of the menus occurs when menus are altered to reflect the needs of the current environment.  This approach may reduce user workload. [Source: Barnes, 1985]

▫ **3.13.9  Use direct manipulation interfaces.**  Direct manipulation interfaces should be used to minimize the impact of a transition to manual control.  [Source: Morrison et al., 1993]

> **Discussion.**  An example of **direct manipulation** is a graphical user interface (GUI).  In direct manipulation, the user controls the interaction with the computer by acting directly on objects on the display screen.  An object may be an icon, menu option, symbol, button, or dialog box. (See Chapter 8 on computer-human interfaces for more information on direct manipulation.)  [Source: Shneiderman, 1998]

# 3.14  Decision aids

> **Definition.  Decision aids** (sometimes referred to as decision support systems) are automated systems that provide support to human decision-making processes either unsolicited or by user request.  Decision aids can narrow the decision alternatives to a few or suggest a preferred decision based on available data. [Source: Wiener, 1988]

▫ **3.14.1  When to use.**  Decision aids should be used

a.     for managing system complexity;

b.     for assisting users in coping with information overload;

c.     for focusing the user's attention;

d.     for assisting the user in accomplishing time-consuming activities more quickly;

e.     when limited data results in uncertainty;

f.     for overcoming human limitations that are associated with uncertainty, the emotional components of decision-making, finite-memory capacity, and systematic and cognitive biases; and

g.     for assisting the user in retrieving, retaining, representing or manipulating large amounts of information, combining multiple cues or criteria, allocating resources, managing detailed information, performing computations, and selecting and deciding among alternatives.  [Source: AHCI, 1998; DISA, 1996]

▫ **3.14.2  When to avoid.**  Decision aids should not be used

a.       when solutions are obvious;

b.       when one alternative clearly dominates all other options;

c.       when there is insufficient time to act upon a decision;

d.       when the user is not authorized to make decisions; or

e.       for cognitive tasks in which humans excel, including generalization and adapting to novel situations.  [Source: AHCI, 1998]

▫ **3.14.3  Let users determine decision aid use.**  Users should be able to determine when and how the decision aid should be used. [Source: Parasuraman & Riley, 1997]

▫ **3.14.4  Use terms and criteria appropriate to users.**  Decision aids should use terminology and criteria appropriate to the target user group.  [Source: DISA, 1996]

▫ **3.14.5  Reduce number of response options.**  Decision aids should reduce the number of response options.  [Source: Barnes, 1985]

> **Discussion.**  The number of options that the user must consider is expected to decrease when a decision aid is used.  Reducing the response options focuses the user's attention onto the most viable options.

▫ **3.14.6  Assist user decisions.**  Decision aids should assist, rather than replace, human decision makers by providing data for making judgments rather than commands that the user must execute.  [Source: AHCI, 1998; DISA, 1996; Parasuraman & Riley, 1997]

▫ **3.14.7  Make support consistent with mental models.**  The support provided by decision aids should be consistent with user cognitive strategies and expectations (mental models).  [Source: NUREG-0700, 1996]

> **Definition.**  A **mental model** is an individual's understanding of the processes underlying system operation.  [Source: NRC, 1998; Parasuraman et al., 1996]

▫ **3.14.8  Do not cancel ongoing user tasks.**  Use of decision aids should not require ongoing user tasks to be cancelled.  [Source: NUREG-0700, 1996]

▫ **3.14.9  Minimize query of user.**  Decision aids should minimize query of the users for information.  [Source: NUREG-0700, 1996]

▫ **3.14.10  Minimize data entry.**  Decision aids should minimize user data entry requirements.  [Source: DISA, 1996]

□ **3.14.11 Provide ability for planning strategy or guiding process.**  Decision aids should be capable of planning a strategy to address a problem or guide a complex process.  [Source: NUREG-0700, 1996]

□ **3.14.12 Accept user direction.**  Decision aids should accept direction from the users on which problem solving strategy to employ when alternative strategies are available.  [Source: NUREG-0700, 1996]

□ **3.14.13 Prioritize alternatives.**  When more than one alternative is available, the decision aid should provide the alternatives in a recommended prioritization scheme based on mission and task analysis.  [Source: AHCI, 1998]

□ **3.14.14 Alert user when unable to process.**  Decision aids should alert the user when a problem or situation is beyond its capability.  [Source: NUREG-0700, 1996]

□ **3.14.15 Be flexible in type and sequence of input accepted.**  Decision aids should be flexible in the types and sequencing of user inputs accepted.  [Source: NUREG-0700, 1996]

□ **3.14.16 Estimate uncertainty and rationale.**  Decision aids should estimate and indicate the certainty of analysis and provide the rationale for the estimate.  [Source: NUREG-0700, 1996]

□ **3.14.17 Make derived or processed data accessible.**  When information used by a decision aid is derived or processed, the data from which it is derived should be either visible or accessible for verification.  [Source: Billings, 1996]

> **Discussion.**  Data that are not critical for operation can be made available only upon request.

□ **3.14.18 Provide hard copy of decision aid use.**  The user should be able to obtain hard copy print outs of data including screen displays, rules and facts, data employed, hypotheses tested, and summary information.  [Source: NUREG-0700, 1996]

□ **3.14.19 Allow access to procedural information.**  Decision aids should give the user access to procedural information used by the aid.  [Source: Morris, Rouse & Ward, 1985; NUREG-0700, 1996]

> **Discussion. Procedural information** is information about the rules or algorithms used by the decision aid. Knowledge of procedural information fosters user acceptance of the aid because the user is able to understand how the aid functions.  As the user becomes more familiar with a given situation, he or she requires less procedural information.  [Source: Morris, Rouse & Ward, 1985]

▫ **3.14.20 Provide user controlled level of explanation detail.**
When the system provides explanations to the user, it should
supply a short explanation initially, with the ability to make
available more detail at the user's request, including access to
process information or an explanation for the rules, knowledge-
basis, and solutions used by the decision aid. [Source: DISA, 1996;
NUREG-0700, 1996]

> **Discussion. Process information** is the information
> about how the aid accomplishes a task. This information
> is required by users to decide whether to use the aid in
> unfamiliar situations and for identifying the nature and
> extent of malfunctions. [Source: Morris et al., 1985]

▫ **3.14.21 Provide clear explanations to user.** When the system
provides explanations to the user, the explanation should use
terms familiar to the user and maintain consistency with the
immediate task. [Source: DISA, 1996]

▫ **3.14.22 Present information with appropriate detail.** Decision
aids should present information at the level of detail that is
appropriate to the immediate task, with no more information than
is essential. [Source: AHCI, 1998]

▫ **3.14.23 Avoid repeated information.** Decision aids should avoid
repeating information that is already available. [Source: AHCI,
1998]

▫ **3.14.24 Integrate decision aids.** Decision aids should be fully
integrated and consistent with the rest of the computer-human
interface. [Source: NUREG-0700, 1996]

▫ **3.14.25 Alert to newly available information.** Decision aids
should alert the user to changes in the status of important system
information such as when critical information becomes available
during decision aid utilization. [Source: NUREG-0700, 1996]

> **Discussion.** Critical information in this standard refers to
> information that may have a significant impact on task
> completion.

▫ **3.14.26 Alert to meaningful events or patterns.** Decision aids
should automatically notify the user of meaningful patterns or
events such as when it predicts a future problem. [Source: AHCI,
1998]

▫ **3.13.27 Predict based on historical data.** Decision aids should
be able to predict future data based on historical data and current
conditions. [Source: AHCI, 1998]

▫ **3.14.28 Provide ability to represent relationships graphically.**
Decision aids should be able to graphically represent system
relationships, its rules network, and reasoning process. [Source:
NUREG-0700, 1996]

□   **3.14.29  Identify simulation mode.**  When decision aids have a simulation mode, entering the simulation mode should require an explicit command and result in a distinguishable change in output.  [Source: NUREG-0700, 1996]

■   **3.14.30  Provide knowledge of intent.**  Each element in an intelligent human-machine system shall have knowledge of the intent of the other elements.  [Source: Billings, 1996; NRC, 1998; Parasuraman et al., 2000]

> **Discussion.**  Monitoring of the system by the user and the user by the system can only be effective if each knows what the other one is trying to accomplish.  [Source: Billings, 1996]

□   **3.14.31  Adapt with situational demands.**  When adaptive decision aiding is used, the level of decision aiding should change with the situational demands in order to optimize performance (See Section 3.13 on adaptive automation).  [Source: Rouse, 1988]

> **Discussion.**  The criticality of a given task can change dramatically depending on the current situation.  [Source: Derrick, 1988]

□   **3.14.32  Adaptive decision aiding implementation.**  Adaptive decision aiding should be applied when resource loading, performance, error frequency, and deviations from intent exceed threshold levels (See Section 3.13 on adaptive automation). [Source: Andes, 1987]

> **Discussion.**  Resource loading, performance, errors, and deviations from intent can be used as indicators to determine when the user might need the help of the automated decision aid.  The threshold levels of these indicators, specifying the optimal time to implement decision aiding may need to be determined on a system-by-system basis, possibly through simulation.

□   **3.14.33  Provide planning assistance.**  Adaptive decision aiding interfaces should allow the user to receive direct assistance in planning how to carry out the intended task.  [Source: Tyler & Treu, 1989]

□   **3.14.34  Allow user to initiate automation implementation.**  The user should be able to initiate automated aids even if system-initiated automation is the norm.  [Source: Billings, 1997; Harris, Hancock, Arthur, & Caird, 1995]

> **Discussion.**  User acceptance of automation centers on whether the user feels in control of the system.  [Source: Rouse, 1988]

# 3.15  Control automation

**Definition.  Control automation** is when the system executes actions or control tasks with some level of autonomy.

▫ **3.15.1  Make automated tasks easily understood.**  When automated control actions are performed, the automated tasks should be easily understood by users and similar to user control actions.  [Source: Billings, 1991]

▫ **3.15.2  Limit control automation authority.**  Control automation should not be able to jeopardize safety or make a difficult situation worse.  [Source: AHCI, 1998]

▫ **3.15.3  Provide appropriate range of control options.** Automated systems should provide the user with an appropriate range of control options that are flexible enough to accommodate the full range of operating conditions for which it was certified. [Source: AHCI, 1998; Parasuraman & Riley, 1997; Sarter & Woods, 1995]

> **Discussion.**  Highly flexible automated systems can be useful when the user knows how to implement the various options across a wide spectrum of operational situations. However, the multiple options that are associated with highly flexible systems also require additional cognitive resources in order for the user to remember which mode is active.  [Source: Woods, 1996]

▪ **3.15.4  Provide immediate feedback.**  To promote successful situation awareness of the automated system, the user shall be given immediate feedback to command and control orders. [Source: Morris & Zee, 1988]

▫ **3.15.5  Allow for different user styles.**  Control automation should be flexible enough to allow for different user styles and responses without imposing new tasks on users or affecting automation performance.  [Source: Wiener & Curry, 1980; Woods, 1996]

▪ **3.15.6  Make available override and backup alternatives.** Override and backup control alternatives shall be available for automation controls that are critical to the integrity of the system or when lives depend on the system.  [Source: Billings, 1991]

▪ **3.15.7  Make backup information easy to get.**  Information for backup or override capability shall be readily accessible.  [Source: Billings, 1991]

▫ **3.15.8  Allow overriding out-of-tolerance conditions.**  When a user might need to operate in out-of-tolerance conditions, then a deliberate overriding action should be possible.  [Source: Billings, 1991]

> **Discussion.**  There may be cases, particularly in an emergency situation, when the user needs to operate in out-of-tolerance conditions.  [Source: Billings, 1996]

**Glossary**

**Adaptive automation**  - The real time allocation of tasks to the user or automated system in a flexible manner, changing the automation to meet current situational demands. Adaptive automation may benefit user performance by allowing the user to remain in active control of the system instead of becoming a passive observer.

**Automation** - A device or system that independently carries out a task that was formerly carried out by a human.

**Automation bias** - When users rely on automated decision aids in a heuristic manner.

**Control automation** - Control automation is when an automated system executes actions or control tasks with some level of autonomy.

**Critical function** - A critical function is a function that can cause system failure when a malfunction is not attended to immediately.

**Decision aids** - Decision aids (sometimes referred to as decision support systems) are automated systems that provide support to human decision-making processes either unsolicited or by user request.  Decision aids can narrow the decision alternatives to a few or suggest a preferred decision based on available data.

**Direct manipulation** - Direct manipulation is when the user controls the interaction with the computer by acting directly on objects on the display screen.  An object may be an icon, menu option, symbol, button, or dialog box. An example of direct manipulation is a GUI.

**Effectively** - Carrying out a task effectively means producing the desired result.

**Efficiently** - Carrying out a task efficiently means that the desired result is produced with a minimum of waste (usually in relation to time).

**Information automation** - Includes information acquisition and integration.  This type of automation would include filtering, distributing or transforming data, providing confidence estimates and integrity checks, and enabling user requests

**Mental model** - A mental model is an individual's understanding of the processes underlying system operation.

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## Index